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Prediction of Rotor-Blade Deformations Due to Unsteady Airloads

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2nd Interim Report

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13. ABSTRACT (Maximum 200 words)

SOFIA, a computer code for aeroelastic computations, was applied to predict the rotor blade deformations due to unsteady airloads caused by BVI and to investigate appropriate control movements to minimize vibration and noise. The computation of the unsteady, compressible, inviscid flow about rotor-blades uses an Euler CFD code, while a quasi one-dimensional structural solver is used to compute the deformation of the rotor blades.

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1. Introduction

During the second period of the contract the attention was focused on the investigation of appropriate active control movements and the quantitative determination of the impact of elastic deformation on the acoustics. Because of the rather expensive numerical simulations-the acoustic propagation effects can only be computed with very dense grids and a small time step (at least 2500 steps for one blade-vortex interaction)- 2D computations were performed to get an idea of appropriate control motions. To validate these preliminary results 3D computations have been carried out as well.

2. Verification and application of the CFD code

As mentioned in the first interim report an experimental study of rotor blade-vortex interaction (BVI) aerodynamics and acoustics was carried out by F.X. Caradonna /1/ at NASA Ames. The vortex was generated externally and interacts with the two-bladed rotor at zero thrust. During the BVI several propagative and convective events occur and the ability to predict these events is a good accuracy test for a CFD method. The experimental blade pressure variations induced by BVI and the comparison with our computations /2/ are very promising and all the important flow features especially the "trailing edge wave" (our terminology) or "secondary BVI wave" (Caradonna's terminology) are captured.
In order to maintain a close relationship during the term of the contract we invited Dr.Caradonna to give a presentation here in Aachen within the international colloquium "Vortex Flows in Aeronautics". Several details about the noise generation have been discussed and further comparisons of computational and experimental results are planned. Especially the tip region (high Mach number) should be investigated carefully because of the 3D effects. Unfortunately in this region $r/R > 0.9$ only a limited number of pressure gages is available to compare with, but a comparison with the farfield data obtained with microphones seems to be feasible.
Based on preliminary computations , the influence of the rotor blade's elasticity on the BVI has been studied (see Figure 1). Within a 2D analysis two parameters concerning the material properties are of importance: the reduced frequency k and a second parameter the ratio of mean density of one cross-section and the density of the surrounding fluid which will be called "inertia parameter". If an airfoil in pitching motion is considered the follwing conclusions can be made. In case the rotational axis is close to the leading edge or at least within the first quadrant, the downwind of the passing vortex induces a positive moment and the compressibility wave as well as the transonic wave are reduced. Unfortunately the computations show that a reduction of BVI-noise is possible only for extreme values of the inertia parameter and the blade's stiffness. As the values for the density of conventional rotor blades are an order of magnitude higher than the minimum values which are required to show any noise reduction, any efforts concerning the modification of material properties are expected to have a minor effect on noise reduction. But nevertheless the pressure waves determined for several test cases show that the wave phenomena of BVI can be influenced by a blade motion and that the study of the blade's elastic motion gives valuable ideas how to apply active control movements without changing the overall vibration level.

/1/ C. Kitaplioglu, F.X. Caradonna: "Aerodynamics and Acoustics of Blade-Vortex Interaction Using an Independently Generated Vortex", paper presented at the American Helicopter Aeromechanics Specialists Conference, San Francisco, 1994

/2/ S. Schlechtriem, D. Nellessen, J. Ballmann: "Elastic Deformation of a Rotor Blade Due to BVI", paper presented at the 19th European Rotorcraft Forum, 1993, Paper No. B1

3. Statement of further research plans

The work to be done focuses now on the three-dimensional calculation of a blade-vortex interaction to enlighten the 3D effects at the rotor blade's tip. Moreover the suggested active control motions designed from 2D considerations will be tested in an 3D environment. First computations show that a grid consisting of 500.000 points is necessary. As mentioned before about 2500 time steps have to be computed to resolve the acoustic waves. With the current CFD method about 50 hours on a Fujitsu S600 are required for only one 3D BVI computation despite a vectorisation level of more than 94 % of the code.

4. Publications

S. Schlechtriem, D. Nellessen, J. Ballmann: "A Numerical Investigation of the Influence of Active Control Movements on Vibration and BVI-Noise", paper presented at the 20th European Rotorcraft Forum, 1994, Paper No. 100

D. Nellessen, S. Schlechtriem, J. Ballmann: "Aeroelastic Computations of Wings", Proceedings of the Fifth International Conference on Hyperbolic Problems, University of Stony Brook, New York, June 13-17, 1994

Time history of the pressure coefficient (location P)

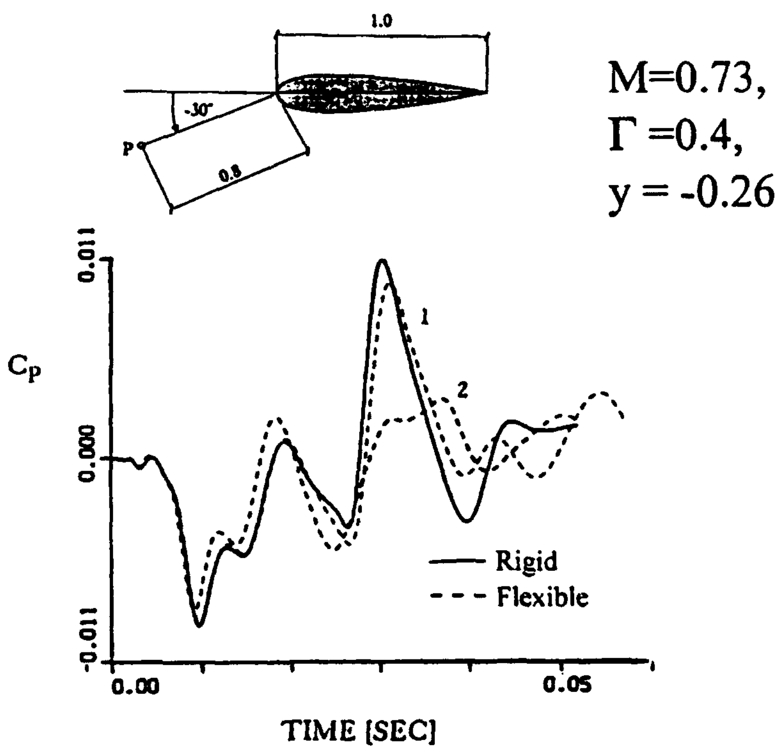

Fig. 1: Influence of the rotor blade's elasticity on BVI noise